21p

N63-10535

CODE 1

NASA TN D-1495

NASA TN D-1495

TECHNICAL NOTE

D-1495

PRELIMINARY EVALUATION OF

TWO JET-TRANSPORT SIMULATORS FOR THE INVESTIGATION OF

LANDING-CONTACT CONDITIONS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON November 1962

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PRELIMINARY EVALUATION OF TWO JET-TRANSPORT SIMULATORS FOR THE INVESTIGATION OF LANDING-CONTACT CONDITIONS

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SUMMARY

In order to determine whether existing jet-transport flight simulators would be suitable for research on factors which affect airplane landing-contact conditions, about 50 landings were recorded on each of two simulators of different manufacture. These simulators were of the type used by the airlines for training or proficiency checks of flight crews. The simulators included visual airport display attachments. Three variables including rate of descent at touchdown, airspeed at touchdown, and, for one simulator only, the increment of normal acceleration at touchdown were determined for comparison with data available for corresponding types of turbojets. The results showed that the simulation of landing contact was inadequate, at least for research applications. For example, the average rates of descent at touchdown were 8.5 and 16 feet per second for the two simulators compared with about 1.5 feet per second for either type of turbojet.

During the tests it was evident that the simulator landings were affected adversely because the pilot received uncertain information from the visual display concerning the altitude just before touchdown. Further, even though the simulators were used in "as is" condition, that is, without any special calibration or adjustment, it is believed that refinements to the simulators would be required to make them sufficiently precise for use in research on factors affecting landing-contact conditions.

INTRODUCTION

Measurements of landing-contact conditions for two types of turbojet transports reported in references 1 to 3 have indicated that the vertical velocities at landing contact for the turbojets were, on the average, about 30 percent higher than for piston-engine transports. For example, the probable vertical velocities at touchdown for 1 landing out of 100 are 3.3 feet per second for propeller-driven piston-engine transports compared with about 4 and 4.5 feet per second for two turbojet transports. The reason for these higher vertical velocities was not apparent. Because of the implications for future transports, it would be desirable to determine the cause of these higher vertical velocities. One method which was suggested for making a study of the effect of various aerodynamic and physical characteristics was to use flight simulators of turbojet transports. However, before such a study could be undertaken, it was necessary to determine how closely the flight simulators could duplicate the landing-contact conditions measured on the actual transports. This investigation was therefore undertaken to measure the landing-contact conditions of two turbojet flight simulators for comparison with measurements recently made on actual turbojets of the same type.

SYMBOLS

a_n	normal acceleration, g units
F_a	aileron control force, lb
F_e	elevator control force, lb
F_r	rudder pedal force, lb
h	altitude, ft
$\dot{h}$	rate of climb or descent as recorded from computer altitude signals, ft/sec
R/C	rate of climb or descent from cockpit-indicator circuit, ft/sec
T	total thrust, lb
V	airspeed, knots
α	angle of attack, deg
β	angle of sideslip, deg
γ	flight-path angle, positive when airplane is climbing, deg
δ_a	aileron deflection, deg
δ_e	elevator deflection, deg
δ_f	flap deflection, deg
δ_r	rudder deflection, deg
δ_s	stabilizer deflection, deg
θ	pitch-attitude angle, deg
$\dot{\theta}$	pitching angular velocity, positive when nose is going up, deg/sec

ϕ angle of bank, deg

$\dot{\phi}$ rolling angular velocity, positive when right wing is going down, deg/sec

Subscripts:

1 low range

2 full range

APPARATUS AND METHOD

Flight Simulators

The two turbojet flight simulators, designated herein as simulator A and simulator B, were of the type used by airlines in training programs for flight crews and were of different manufacture. Each of the flight simulators was designed to simulate the complete flight regime of a particular jet transport. The cockpits were identical to the airplane cockpits. Cockpit-motion cues in pitch and roll were provided. Cockpit instruments functioned as in flight, in accordance to the static and dynamic airplane response to control inputs. Control forces were also simulated. These functions were generated with electronic analog computing equipment and supplementary hydraulic and mechanical devices.

The visual display attachments provided the pilot with a view of an airport and with a field of vision about 45° in width; the image of an airport was projected on a theater-size screen. The projected image was produced by closed-circuit black-and-white television. The television camera moved along the simulated flight path with respect to a two-dimensional picture of the airport in response to signals from the computer section of the simulator. Simulated breakout altitude (i.e., the altitude at which the visual airport display is turned on) was adjustable up to 1,000 feet.

Test Procedure

For these simulator validation measurements, straight landing approaches were made from an altitude of about 1,000 feet above the airport. The runs were started on ILS guidance slightly outside the breakout point; in these runs, the breakout point was at an altitude of at least 600 feet and was at least 30 seconds before touchdown. The simulated airplane weight was set at approximately 90 percent of the maximum permissible landing weight. Cockpit motion was on. The landing approach was usually made with full flap deflection and a constant throttle setting.

Crew Qualifications and Utilization

Over 50 landings were recorded with each simulator. The usable landings of simulator A were made by three pilots; however, most of the landings were made by the simulator supervisory pilot most experienced with this simulator and its visual airport display. A copilot and an engineer-observer were usually present in the cockpit during the tests. There were 10 recording sessions of 1-hour duration with an average of 7 attempted landings per session.

The usable landings of simulator B were made by 20 pilots of the corresponding type of turbojet. These pilots included seven jet-transport airline crews, the simulator check pilot, simulator instructors, and flight instructors, all of whom were volunteers. Data were obtained from 11 recording sessions which averaged 30 minutes. An average of five landings was obtained per session, some by the captains and some by the first officers or instructor pilots. Under these circumstances, a negligible amount of time was available for familiarization with the handling characteristics peculiar to the flight simulator or with the visual airport display.

Instrumentation

The simulator landings were recorded on multiple-channel oscillographs. Continuous records were taken at paper speeds of 0.2 to 0.8 inch per second with timer indications at 1-second intervals. In most cases, d-c voltages proportional to quantities which were to be measured were readily available in the computer sections of the simulators. However, in order that the variation of one or two parameters on simulator A could be measured, high-precision rotary potentiometers were coupled to computer servos and were supplied with a 100-volt direct current from the simulator power supply. In general, as many channels of information were recorded as were readily available. In the runs with simulator A, up to 10 channels of information were recorded; with simulator B, 18 channels of information were recorded. The measured variables and approximate trace sensitivities for each case are included in table I.

RESULTS AND DISCUSSION

Results from simulators A and B are compared with results from the two types of turbojet transports reported in references 1 to 3 and designated herein as turbojet A and turbojet B.

Simulator A

A time history of a landing of simulator A is shown in figure 1. This figure shows the descent from an altitude of approximately 100 feet. It will be noted that this landing approach was rather flat, with little, if any, attempt to flare. The rate of descent at touchdown determined from the flight-path angle γ and the airspeed V was 9 feet per second. The response of the rate-of-descent signal was found to be too sluggish to be reliable at touchdown. Further discussion of why the flight-path-angle signal was used to determine rate of descent at touchdown is given in the appendix.

The most noticeable feature of the time history is a lateral oscillation with a 7-second period. This oscillation was frequently present during landing runs with half-amplitudes of bank angle ranging from about 1° to 4°. The pilots did not comment about a lateral oscillation as such but did say that it was extremely difficult to maintain the heading manually during landing approach. Therefore, the heading-control mode of the autopilot was nearly always used during the landing approach to reduce the difficulty in maintaining heading. However, the autopilot was not used in the run shown in figure 1.

It should also be emphasized that for at least half of the simulator landings, including the case of figure 1, nose-wheel contact was indicated at touchdown. However, the actual airplane landings are normally made on the main landing gear with the nose wheel held off the ground.

The frequency distributions of figure 2 show distributions of rate of descent at touchdown as determined from $V\gamma$ for 29 landings and distributions of airspeed at touchdown for 55 landings. These data are shown as probability-distribution plots in figures 3 and 4. Also shown in these figures are probability distributions for turbojet A based on 40 landings. These data are from measurements taken at the New York International Airport. (See ref. 1.) The results of figure 3 indicate that the rate of descent at touchdown for the simulator landings was much greater than for the turbojet landings. For example, for 1 landing in 100, the indicated rates of descent are 4 feet per second for the turbojet and 16 feet per second for the simulator. The mean rates of descent were about 1.5 feet per second for the turbojet and 8.5 feet per second for the simulator.

The probability curves of figure 4 for airspeed at touchdown indicate that the simulator performance was fairly well matched to that of the turbojet. The mean touchdown airspeed was 126 knots for the turbojet and 132 knots for the simulator.

Simulator B

The landing time history of figure 5 is typical of the majority of runs conducted on simulator B. The time history shows that an average rate of descent of approximately 19 feet per second or over 1,100 feet per minute was maintained from an altitude of 400 feet to touchdown. This rate of descent was nearly twice the normal practice in flight. The landing approaches were usually marred by a spurious longitudinal oscillation with a period of 4 to 8 seconds. The effect of this oscillation was such that the rate of descent at touchdown was increasing sharply in about half of the landings. The oscillograph records also show a rolling oscillation of about the same period with a half-amplitude of bank angle up to 5°. This lateral oscillation was not particularly noticeable to those in the cockpit. Apparently, it was partially masked by the abnormal pitching oscillation.

Measured landing-contact conditions for 48 landings of simulator B are summarized in the frequency-distribution graphs of figure 6. The figure shows frequency distributions of rate of descent, airspeed, and increment of normal acceleration at touchdown.

The probability distributions of figures 7, 8, and 9 compare landing-contact conditions of simulator B with turbojet B. The turbojet data from reference 2 were measured at Los Angeles International Airport. Figure 7 shows that rates of descent for the simulator landings were very much greater than for the turbojet. For example, the average simulator touchdown rate was 16 feet per second as compared with a rate less than 1.5 feet per second for the turbojet. One simulator landing in 100 would exceed 30 feet per second, compared with a value of about 4.5 feet per second for the turbojet. Figure 8 shows that the airspeeds at touchdown for the simulator landings were somewhat higher than for the turbojet and that they covered a much wider speed range. The mean landing speeds were 133 knots for the simulator and 118 knots for the turbojet. The airspeed at touchdown for the simulator for 1 in 100 landings was 170 knots, compared with 137 knots for the turbojets. Figure 9 indicates that the increments of normal acceleration at touchdown were also much greater for simulator B than for the corresponding turbojet. The mean values were 0.8g for the simulator and 0.3g for the turbojet. One landing in 100 would produce an incremental acceleration of 2.4g for the simulator and 0.65g for the turbojet.

General Observations

The results for both simulators A and B indicated that without improved characteristics, these simulators cannot be used for a study of factors affecting landing-contact conditions. Before this refinement could be accomplished, however, further investigation would be required to determine how well the simulators duplicated the aerodynamic, stability and control, and performance characteristics of the actual turbojet transports in the landing approach.

An indication of some deficiencies in the simulation was apparent during the tests. For example, it was evident to cockpit observers that the results were adversely influenced by the limitations of the visual airport displays. In this regard, most of the pilots were critical of the lack of apparent depth perception. Perhaps the greatest weakness of the visual displays was the uncertain sense of height presented to the pilot just before touchdown.

Measurements of various flight parameters and the behavior of the simulators during landing also suggested that there were discrepancies in the dynamic flight characteristics of the simulators in the landing configuration. It was extremely difficult to maintain a heading with manual control in simulator A. In simulator B, a spurious longitudinal oscillation was usually present. In both simulators, a lateral oscillation was usually present, even though it was not obvious to those in the cockpit.

The recorded oscillograph data also showed some evidence of discrepancies in rate-of-descent information at various points in the simulator computers. These data are discussed briefly in the appendix.

CONCLUDING REMARKS

In order to determine whether existing jet-transport flight simulators would be suitable for research on factors which affect airplane landing-contact conditions, about 50 landings were recorded on each of two simulators of different manufacture. Both simulators and the attached visual-airport presentations were used in "as is" operating condition without any special calibration or adjustment. The results show that the vertical velocities at touchdown for both simulators were much greater than for the corresponding types of turbojets. The performance of the simulators at landing contact could probably be improved to some extent by extensive and precise adjustment of the simulators. However, it is believed that modification of both the simulators and the visual landing displays would be required to obtain fidelity of landing simulation suitable for research on landing-contact conditions.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 30, 1962.

APPENDIX

COMPARISON OF RATE OF DESCENT FROM VARIOUS SIMULATOR-DATA SOURCES

Simulator A

Rate-of-descent information was available from several sources in the simulator computer. Four of these signals were recorded and three of them can be seen in the landing time history of figure 1. Included were the signals which drive the cockpit rate-of-climb indicator, two altitude signals, full range (60,000 feet) and low range (1,000 feet), and the flight-path-angle γ signal which can be multiplied by the airspeed to get vertical velocity. It was found that the rate-of-climb signal appeared to be overdamped at touchdown but indicated a rate of climb as soon as rotation for take-off was initiated. The full-range altitude signal would have to be accurate to better than 1 part in 10,000 to be sufficiently accurate for this purpose. As might be expected, this signal was found to be frequently in error by about 40 feet at touchdown. The low-range-altitude signal was suspect because it always indicated a smoothly flared landing. When it was found that none of these three signals was satisfactory for determining vertical velocity at touchdown, the γ signal was added to the records. The dynamic response of this signal was found to be acceptable; therefore, it was used for the source of rate-of-descent values at touchdown.

The results of cross-checks on rate of change of altitude determined during steady climb or descent from four sources on the simulator computer are indicated in the following table. (The values from the low-range and full-range altitude signals are indicated by $\dot{h}_1$ and $\dot{h}_2$, respectively.)

$\dot{h}_1$, ft/sec	$\dot{h}_2$, ft/sec	R/C, ft/sec	$V\gamma$, ft/sec
-7.5	-6.25	-6	-5.5
-15	-12.5	-11	-10.6
22	19	17	16.5

These data show a consistent discrepancy of about 30 percent at different points in the simulator computer, and it appears likely that this discrepancy affects the quality of landing simulation. It should be noted that the discrepancy between the $\dot{h}_1$ and $V\gamma$ values here is in the opposite direction to the one indicated in a typical time history such as figure 1 for rate-of-descent values at touchdown.

Simulator B

Rate-of-descent values at touchdown consistent within about 10 percent were obtained from three recorded signals or combinations of recorded signals. During pitching oscillations, that is, with nonstatic conditions, consistent rates of descent were obtained from the rate-of-descent trace, the rate of change of the low-range-altitude trace, and from $V(\theta - \alpha)$. The flight-path-angle values measured directly were found to be in error by a factor of approximately two, compared with the γ values determined from $\theta - \alpha$ which have been shown to be approximately correct. The reason for the discrepancy in the γ values is unknown.

REFERENCES

1. Stickle, Joseph W.: An Investigation of Landing-Contact Conditions for Several Turbojet Transports During Routine Daylight Operations at New York International Airport. NASA TN D-1483, 1962.

2. Stickle, Joseph W.: An Investigation of Landing-Contact Conditions for Two Large Turbojet Transports and a Turboprop Transport During Routine Daylight Operations. NASA TN D-899, 1961.

3. Stickle, Joseph W., and Silsby, Norman S.: An Investigation of Landing-Contact Conditions for a Large Turbojet Transport During Routine Daylight Operations. NASA TN D-527, 1960.

TABLE I.- APPROXIMATE INSTRUMENT-TRACE SENSITIVITIES

USED FOR SIMULATORS A AND B

Measured variable	Approximate sensitivities, per inch of trace deflection	
	Simulator A	Simulator B
Normal acceleration, a_n, g units	2[a]	0.6
Low-range altitude, h_1, ft	500	144
Full-range altitude, h_2, ft	250	------
Rate of climb or descent, R/C, ft/sec	4	50
Airspeed, V, knots	110	98
Aileron control force, F_a, lb	----	41
Elevator control force, F_e, lb	----	47
Rudder pedal force, F_r, lb	----	68
Total thrust, T, lb	----	30,000
Angle of attack, α, deg	----	4.8
Angle of sideslip, β, deg	----	4.5
Flight-path angle, γ, deg	4.75	8.5
Aileron deflection, δ_a, deg	----	9.3
Elevator deflection, δ_e, deg	10	6.7
Flap deflection, δ_f, deg	----	25
Rudder deflection, δ_r, deg	----	8
Stabilizer deflection, δ_s, deg	----	1.6
Pitch-attitude angle, θ, deg	----	5.25
Pitching angular velocity, $\dot{\theta}$, deg/sec	5	------
Angle of bank, ϕ, deg	----	13
Rolling angular velocity, $\dot{\phi}$, deg/sec	10	------
Nose-wheel contact	Yes	No

[a]Lift-to-weight ratio.

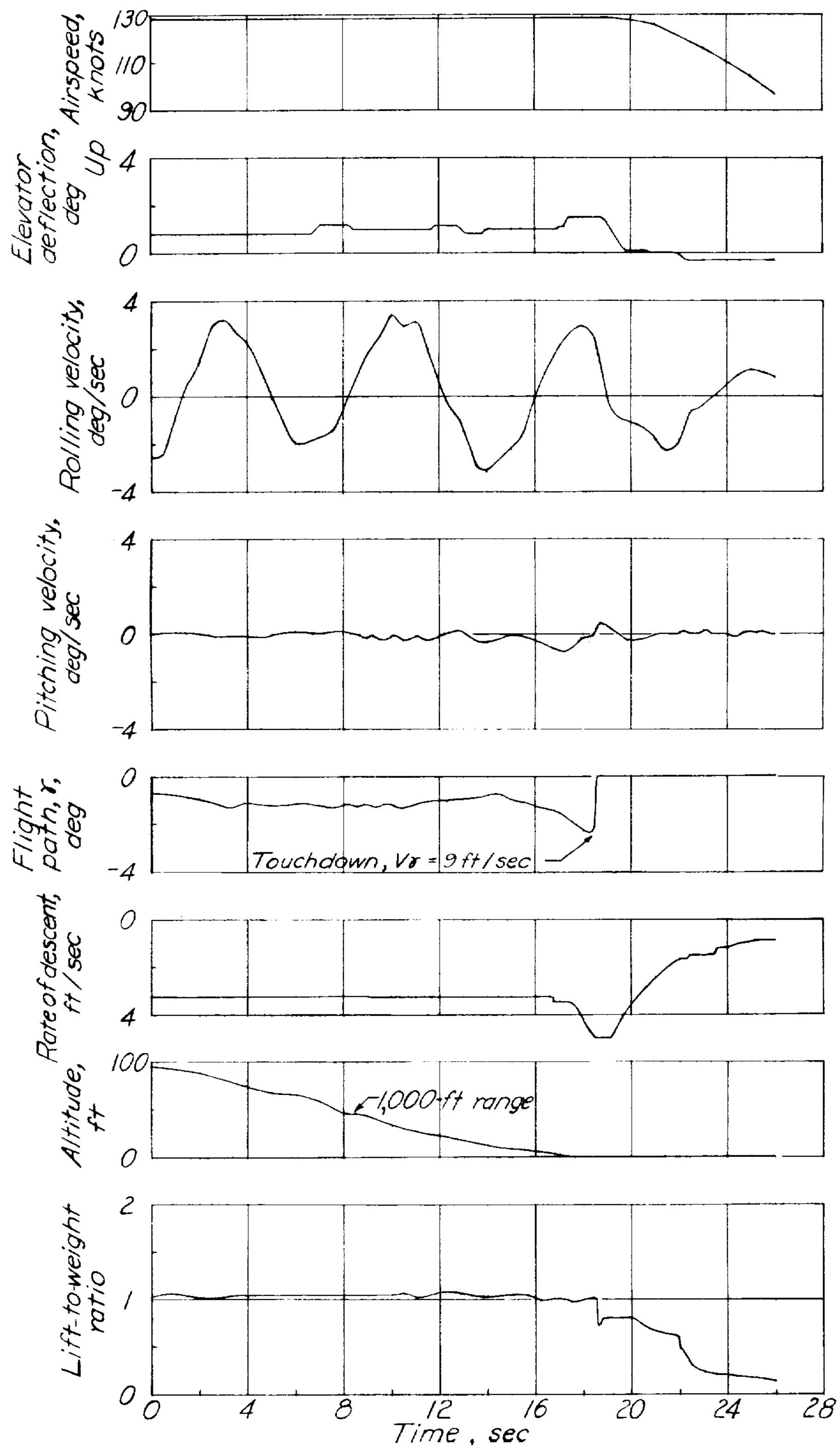

Figure 1.- Time history of a landing of simulator A.

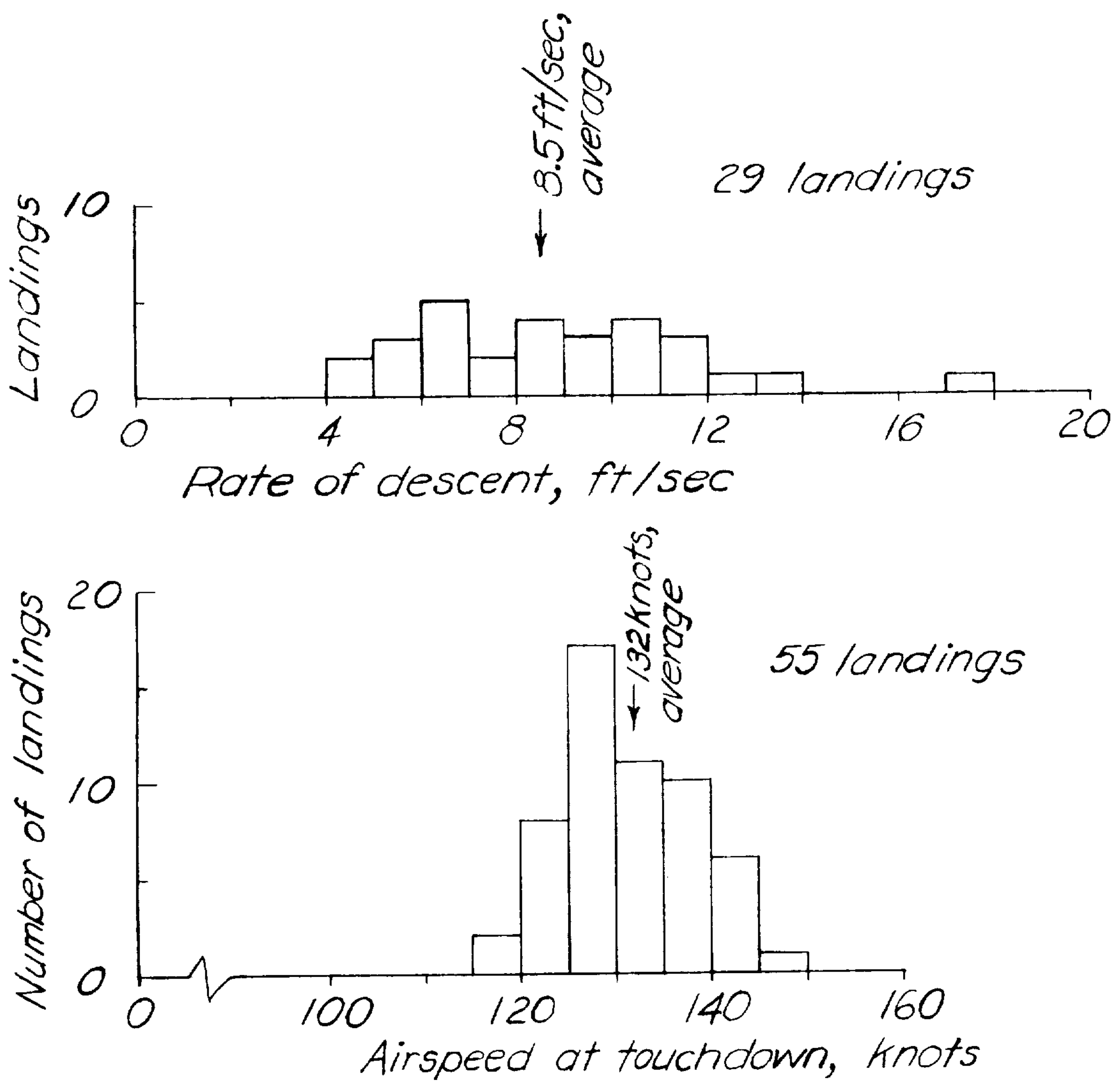

Figure 2.- Frequency distributions of rate of descent determined from $V\gamma$ and of airspeed at touchdown for landings of simulator A.

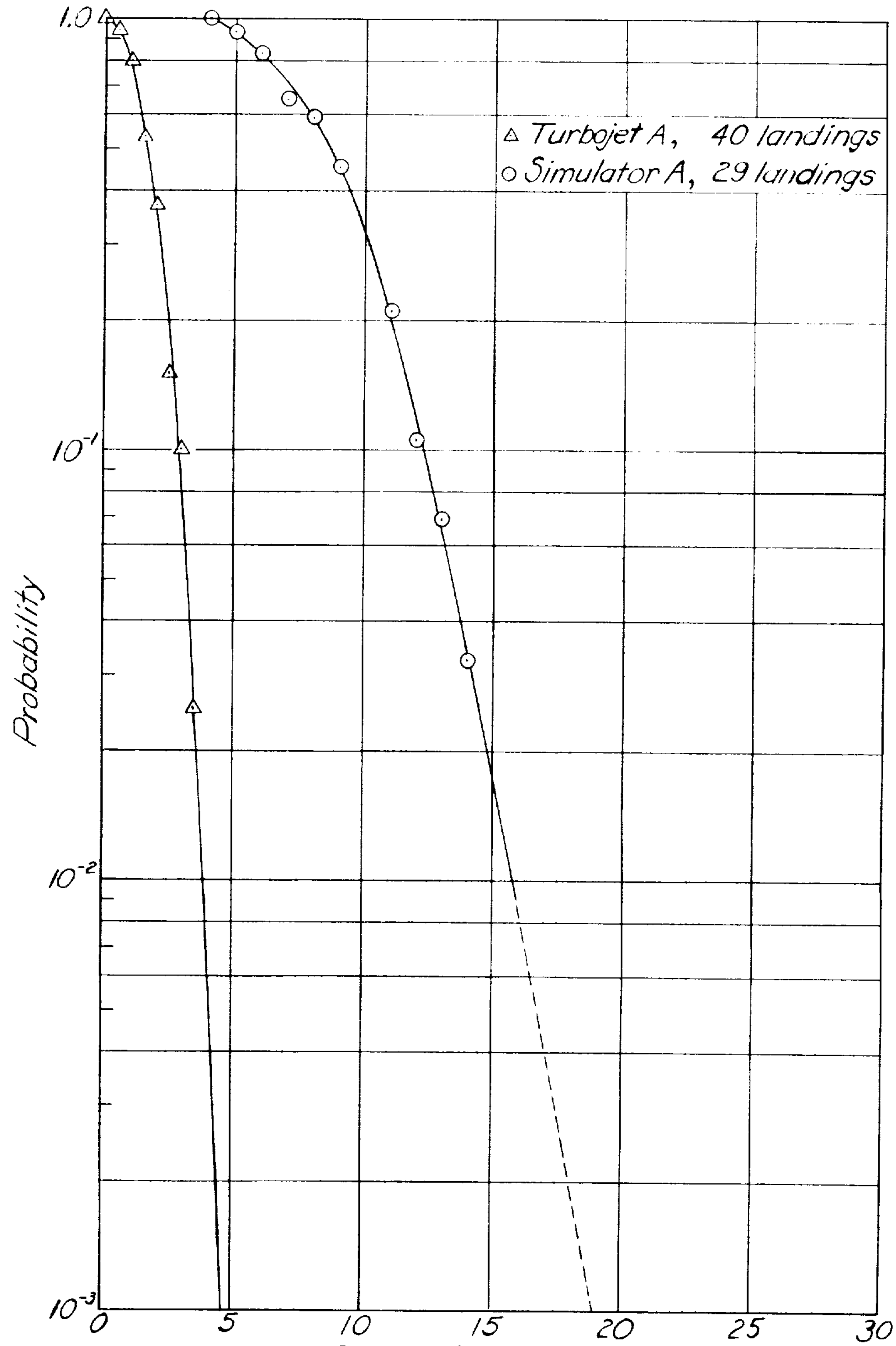

Figure 3.- Comparison of probability distributions of rate of descent at touchdown for simulator A and for turbojet A.

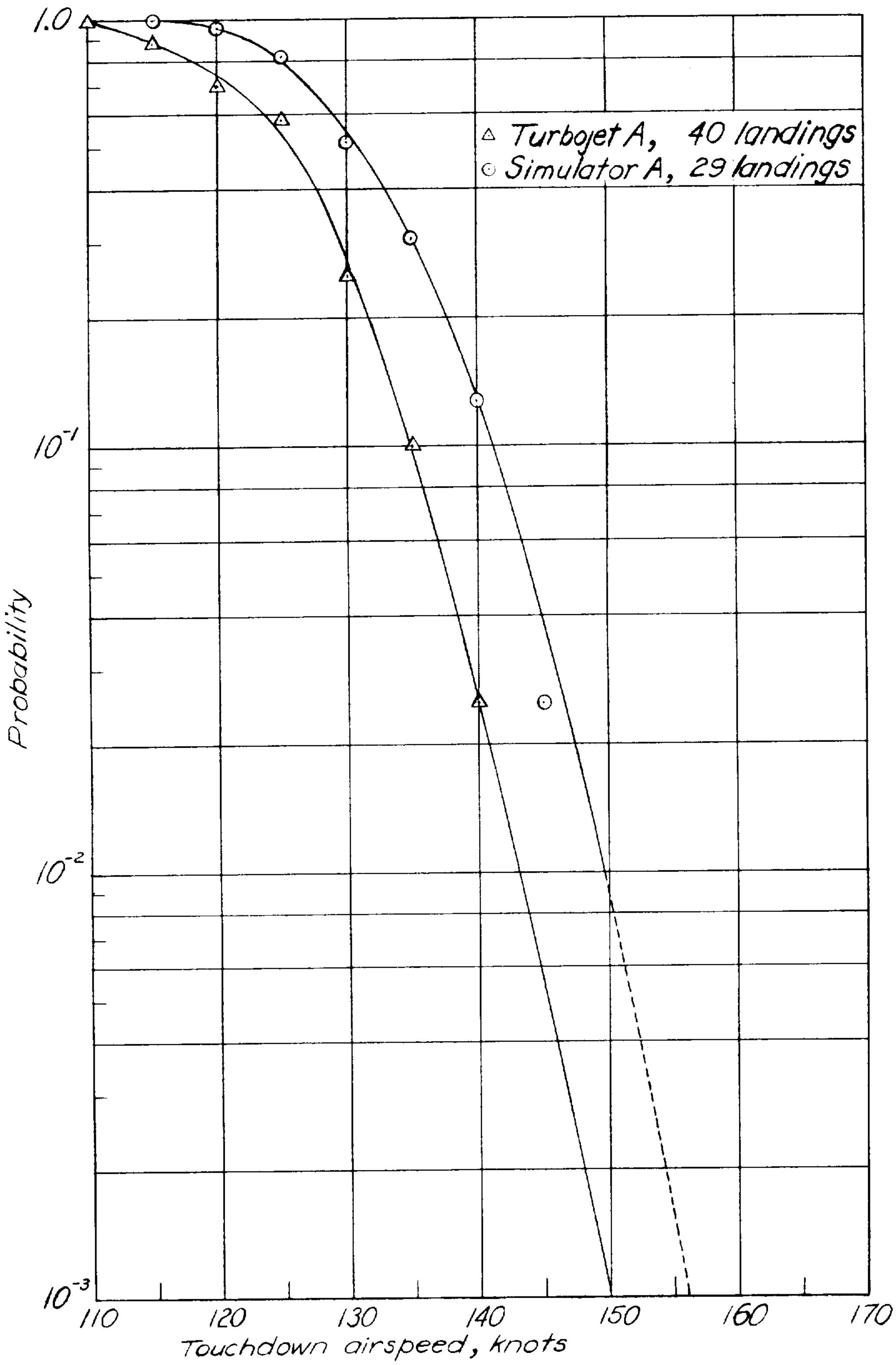

Figure 4.- Comparison of probability distributions of airspeed at touchdown for simulator A and for turbojet A.

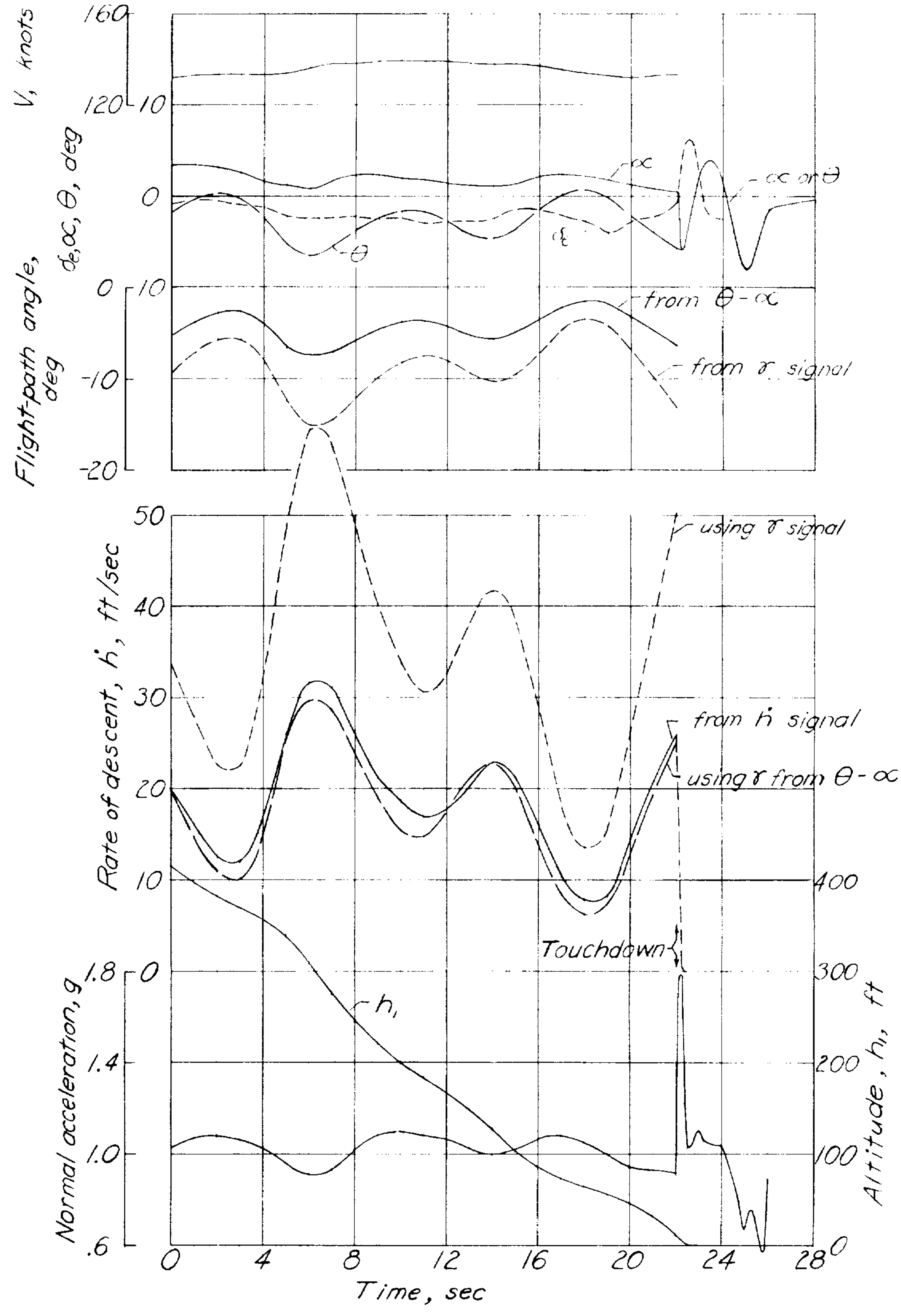

Figure 5.- Landing time history of simulator B.

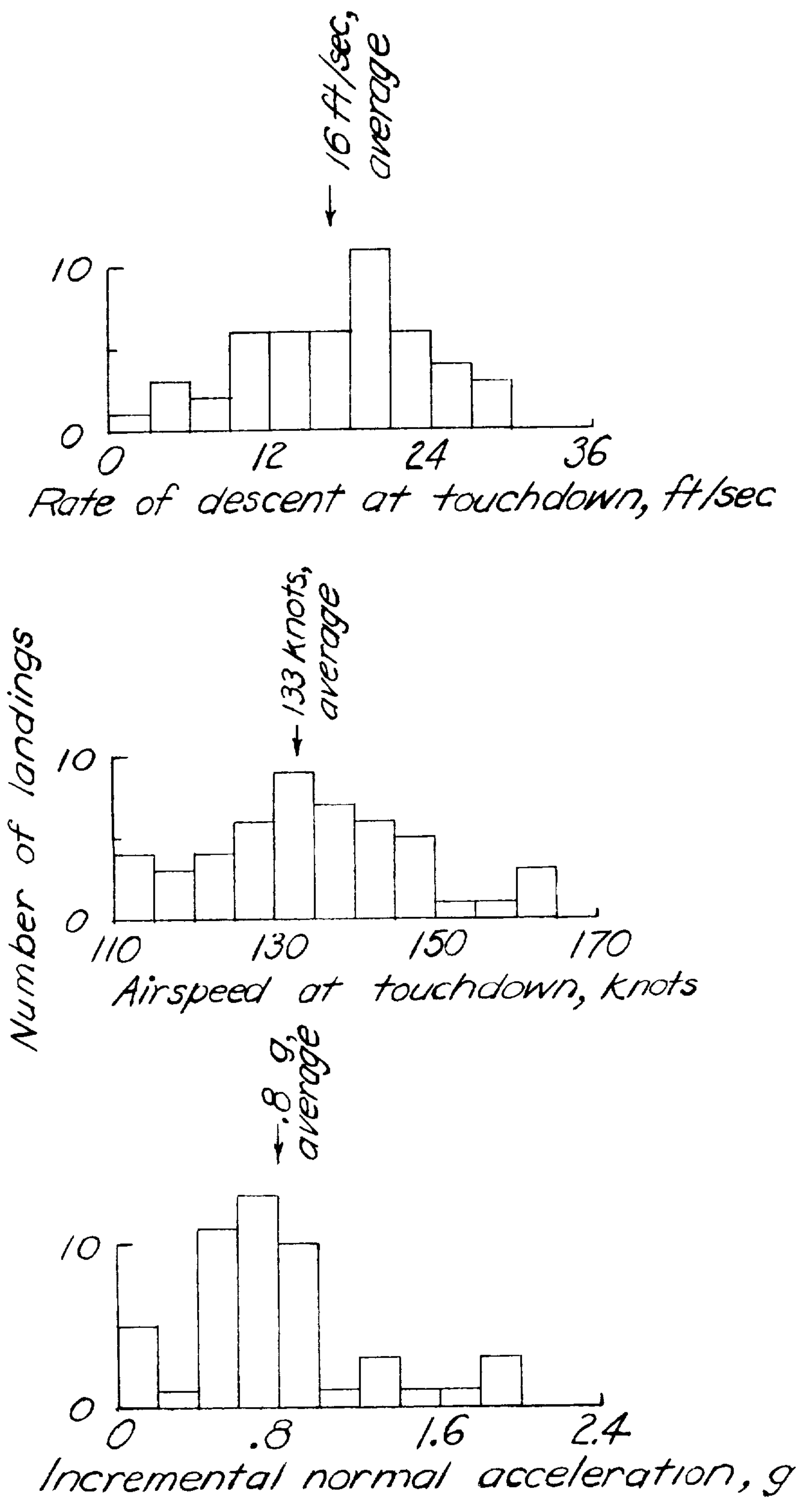

Figure 6.- Results of 48 landings for simulator B.

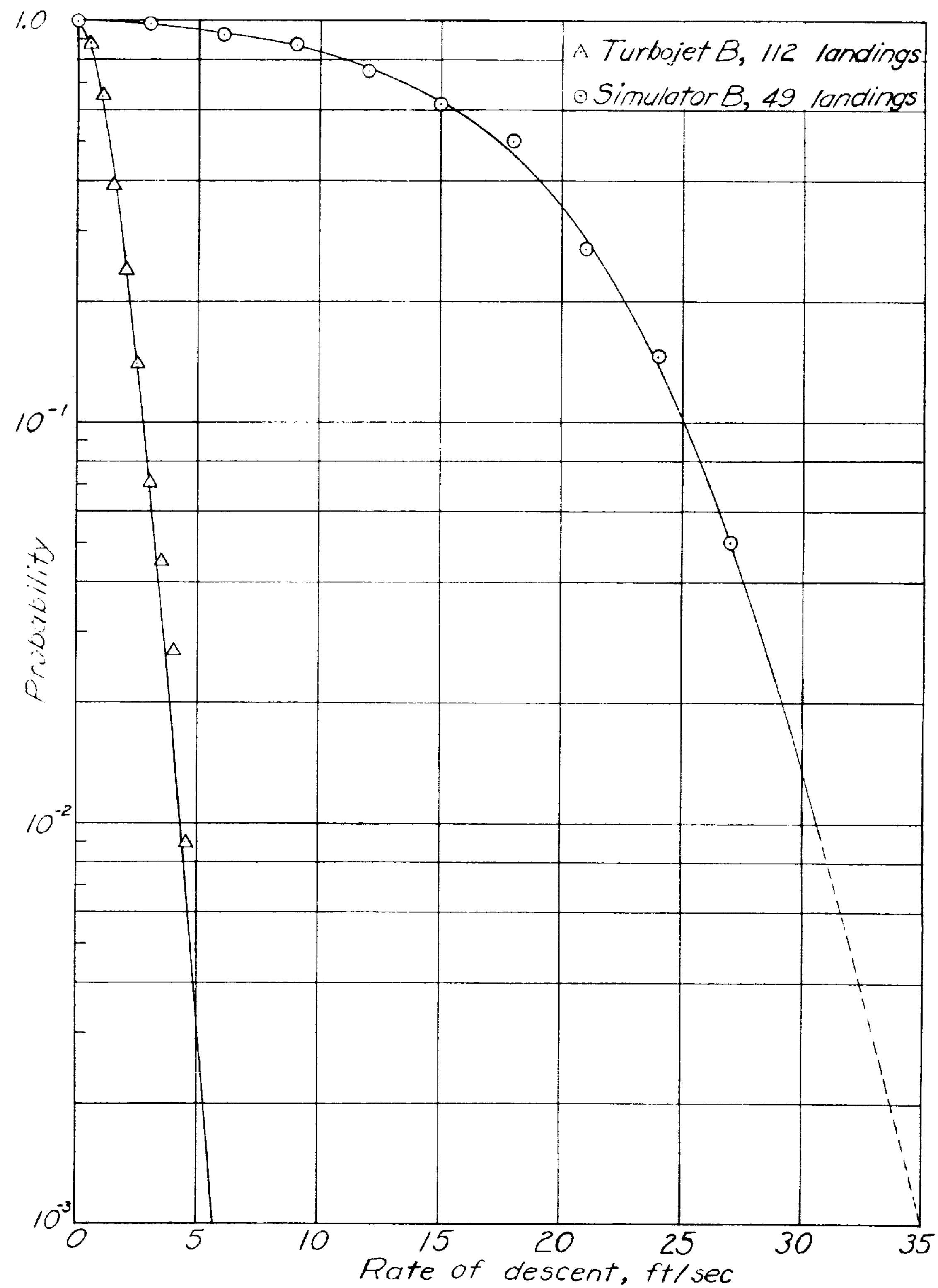

Figure 7.- Comparison of probability distributions of rate of descent at touchdown for simulator B and for turbojet B.

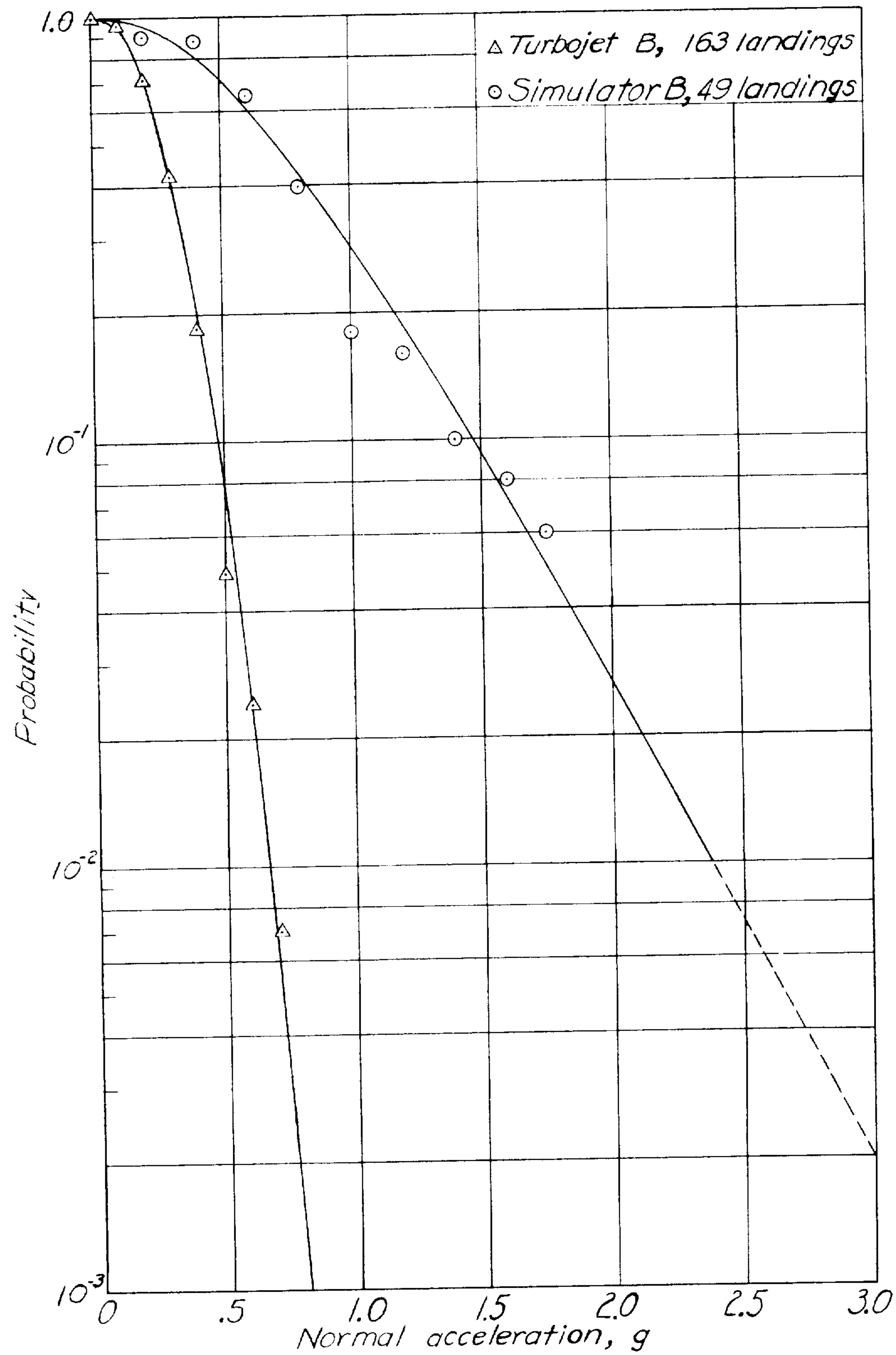

Figure 9.- Comparison of probability distributions of incremental normal acceleration at touchdown for simulator B and for turbojet B.

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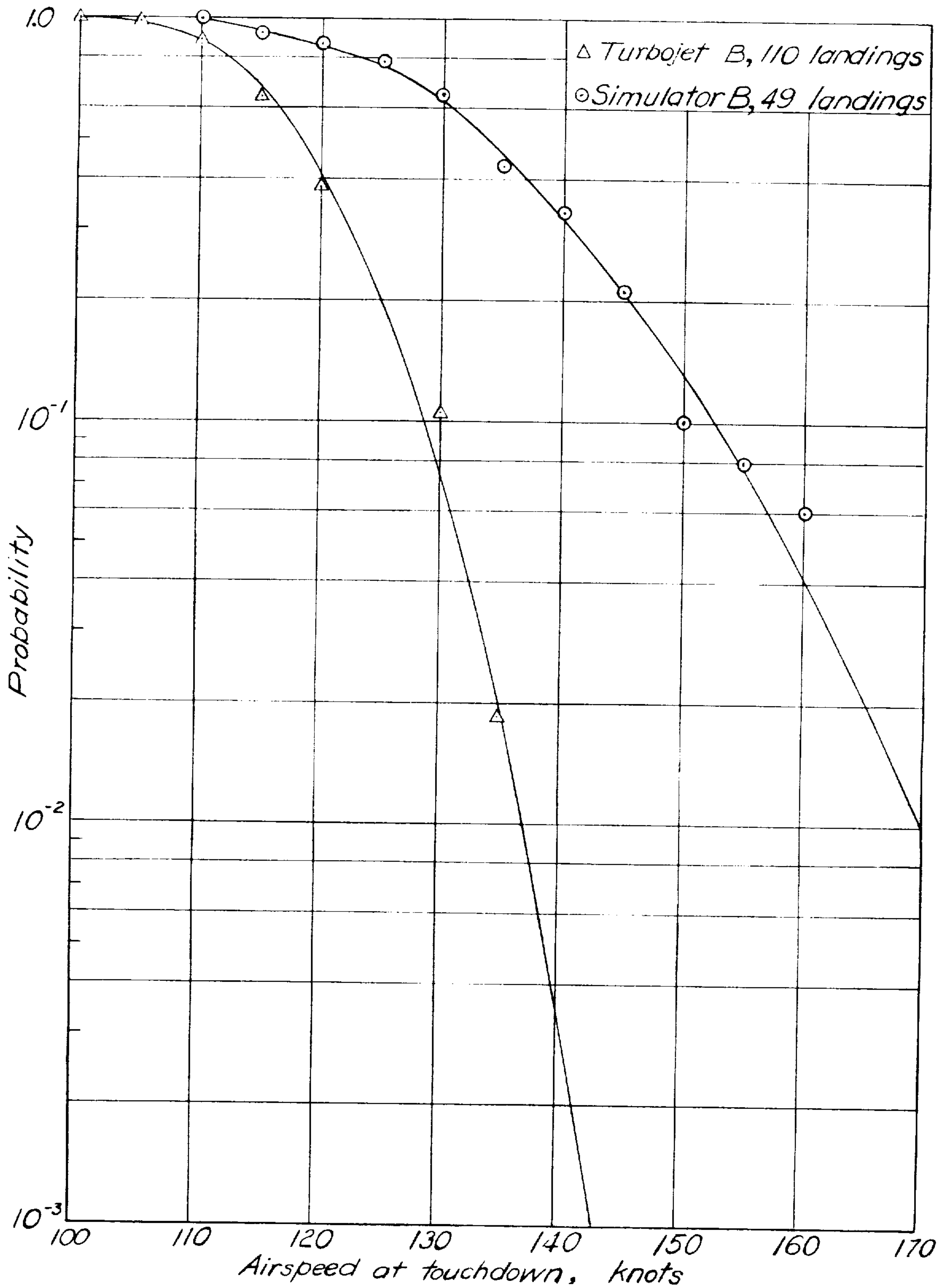

Figure 8.- Comparison of probability distributions of airspeed at touchdown for simulator B and for turbojet B.